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TECHNICAL MEMORANDUMS

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LANDING IMPACT OF SEAPLANES

By Wilhelm Pabst

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 624

LANDING IMPACT OF SEAPLANES*

By Wilhelm Pabst

I. Introduction

Long experience affords plenty of data on take-off and seaworthiness problems for the construction of float seaplanes of normal size. The designing of large flying boats and the resulting change in the type of construction and aerodynamic characteristics call for a thorough theoretical and experimental investigation of the various factors affecting take-off and seaworthiness. This would enable designers to find the best solution for each case and to avoid costly errors. The alighting or landing impact, one of the most important questions of seaworthiness, is considered below. A D.V.L. (Deutsche Versuchsanstalt für Luftfahrt) report of January, 1928, contained theoretical calculations, which were further developed and published in an early issue of this year's Zeitschrift für Flugtechnik und Motorluftschiffahrt.* The calculations will be briefly considered here, without going into details, and the tests will be described.

II. Synopsis of the Landing-Impact Theory

In general, impacts are produced by the collision of two bodies having different speeds. In the case of the landing impact, the two bodies are the seaplane and the mass of water accelerated while landing. Figure 1 shows a difficult but quite possible landing in seaway 2. The seaplane lands at the angle of attack of maximum lift and, with tail down, strikes a wave head-on. The mass of water to be accelerated at the instant of landing depends on the pressure of the colliding bottom portion, which has the width of the float or hull and a certain length a. The energy of the flow is represented by the energy of a specific mass of water which has the velocity of the float bottom. For an

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*"Über den Landestoss von Seeflugzeugen." From Zeitschrift für Flugtechnik und Motorluftschiffahrt, January 14, 1931, pp. 13-27. Verlag von R. Oldenbourg, München und Berlin.

**W. Pabst, "Theorie des Landestosses von Seeflugzeugen." Zeitschrift fur Flugtechnik und Motorluftschiffahrt, May 14, 1930, pp. 217-226. (For translation, see N.A.C.A. Technical Memorandum No. 580.)

infinitely long bottom, or a portion of it, i.e., for a two-dimensional problem, a calculation is possible by disregarding certain points of minor importance which will not be considered here. The impact-pressure potential used in this connection leads to formulas similar to those of a plate potential. The volume of the accelerated water mass is then half the volume of a cylinder of a diameter equal to the width of the float bottom. In practice, the bottom cannot, however, be considered as part of a plate of infinite length since, in this problem, the flow about the edges cannot be disregarded.

Considering the difficulty of three-dimensional problems, the water mass accelerated by rectangular plates of various aspect ratios was determined experimentally. Without going into details, certain test values are plotted in Figure 2 against the aspect ratio. The curve is an empirical function based on the tests. The straight dash line represents the values for the two-dimensional problem in which the flow about the edges is neglected. As shown by the curves, however, its influence is quite important in the considered region $a/b = 1$ to 2.

In establishing the equations of motion, it must be borne in mind that the impact is affected decisively by the elasticity of the body. This applies to the landing impact of seaplanes, at least of those with flat or slightly V-shaped bottoms, as already shown by Seewald's momentum theory.

Even when the impact force remains finite, irrespective of elasticity, it must be investigated as to whether the airplane is rigid under the action of the impact. The investigated system is assumed to consist of two masses connected by a spring, a periodically quick-varying force acting on one of the two masses. This force is a function of the time, but is at first independent of the mass, mass distribution and elasticity of the system. The equations of motion are then established in the form of forced vibrations, after resolving the force into Fourier's series as a function of the time.

The result shows that the accelerations of the two masses are approximately similar, only when the natural vibration number of the system is at least four to five times greater than the smallest force vibration which must be taken into consideration. If, according to this definition, the system is not rigid and if the landing impact is a function of the mass, the mass distribution and elasticity of the system must also be considered. Since, according to measurements described below, the impact pressures on stiff bottoms reach frequencies of 70 to 100 Herz or more, it is obvious that the elasticity cannot be neglected, even if a finite impact force is produced by a flat V bottom, elas-

ticity being disregarded in that case. Even rigidly built flying boats form no exception, since the inherent vibration coefficients of the wings, usually with great decentralized masses, engines, tanks, etc., are rather small, i.e., of the order of 5 to 10 Herz. A purely hydrodynamic study of the landing impact is therefore seldom complete. It is admissible for very sharp V bottoms which, however, are seldom encountered in practice.

The above statements are confirmed by experience. The marked decrease of impact accelerations toward the top is accounted for only by the fact that the airplane is not rigid, but a system of elastically combined masses. These theoretical considerations are confirmed by the fact that float bottoms break first at their stiffest points near the bulkheads. Figure 21 shows a typical bottom break near a bulkhead. The simplest arrangement, on which equations of motion are based, is shown in Figure 3. M_1 is the mass of the seaplane which, in this first approximation, is still rigid. The seaplane mass is connected by a spring with the bottom, assumed to have no mass, which sets the water mass M_2 in motion. By approximation this method can be extended to V bottoms or any other bottom type. For a given depth of immersion, a water mass is then considered, which corresponds to the displacement of a flat bottom of the same width as the submerged bottom portion. Taking the elasticity into consideration, but disregarding the damping, the general equations of motion are

$$M_1 \frac{d^2 x_1}{dt^2} = k f,$$

$$\frac{d \left(M_1 \frac{d x_2}{dt}\right)}{d t} = - k f,$$

where $x_1 - x_2 = L - f$.

For the flat bottom M_2 = constant, and for the V bottom $M_2 = c x_2^2$. The general expression for any float bottom is $M_2 = f(x_2)$. It can always be graphically or numerically integrated. Closed integrations were carried out in two limiting cases, one for a flat bottom and the other for a sharp V bottom.

The equation was slightly extended for the flat bottom. The aircraft was further subdivided into two compound elastic masses such as fuselage, engine and floats for a float seaplane, or hull, wing and engine for a flying boat. The solution leads to compound vibrations. The results are given in Appendix I. Numerical or graphical methods of calculation should be used for systems with several masses. In general, a certain number of

questions can be answered, at least approximately, by the formulas for the system with two masses. The subdivision into rigid individual seaplane components connected by springs involves a certain risk, since the elasticities are distributed over the whole system of masses. A closer survey shows, however, that small elasticities affect the result less than more pronounced elasticities, the calculation thus still retaining the value of a numerical estimate. An accurate calculation is useless, owing to the lack of reliable data on external conditions, such as seaway, and manner of landing. The accuracy is favorably affected by the fact that the elasticities or spring constants are introduced into the calculation as square roots.

The equations were also integrated in another limiting case, that of the sharp V bottom, in which elasticity is neglected and the seaplane considered as a rigid structure. In the first report the calculation was made for very large waves and hence for great colliding bottom lengths. A comparison with American tests showed the desirability of including small waves. Formulas for all kinds of seaways are therefore given in Appendix 2. They were obtained by the following method. The experimentally determined mass of water and its graphically obtained first derivative according to the width were expressed by empirical functions over the whole region and introduced into the calculation. These formulas for the sharp V bottom are chiefly applicable to the limiting cases. Seaplanes with such sharp V bottoms have not yet been built in Germany, such bottoms being unfavorable for the take-off of heavily loaded seaplanes. The impact forces of flat V bottoms are approximately determined by the two limiting cases, as shown by the numerical calculation.

III. Numerical Calculation

Two other questions must be answered for the practical application of the formulas. One concerns the magnitude of the factors of elasticity, and the other concerns the length of the bottom colliding with the water and the relative speed between the float bottom and the water (i.e., the seaplane speed with respect to the water), at the instant of landing.

As already mentioned, the determination of marked elasticities is usually sufficient. Numerical estimates can be made in certain cases for the elasticity of the float bottom, wing, etc. In other cases, as for the determination of the elasticity between fuselage and float, the desired values must be determined experimentally. This is achieved by vibration tests. The seaplane is elastically suspended and the natural vibrations of the various structural members are rendered visible by resonance

with the number of revolutions of a rotating inert mass. For the determination of the elasticity between float and fuselage, the r.p.m. of the inert mass is determined, at which the float accomplishes relative motions with respect to the fuselage in resonance with the r.p.m. of the inert mass. The elasticity or spring constants of structural members can be calculated by means of well-known vibration formulas from this inherent vibration coefficient and from the masses or inertia moments of fuselage and floats. The test was made on a Heinkel monoplane. The measured values were used for a numerical calculation, the results of which are given below. Further tests will show whether the elasticities of other aircraft have approximately the same magnitude.

The area of the colliding bottom surface and the relative speed between the float bottom and the water are decisively affected by the seaway and by the manner of landing. This problem involves many difficulties, due to the great variety of the seaways (which change in wave shape and length according to the force and duration of the wind, the length of the unobstructed wind path and the depth of the water), and to the many different ways of landing. A solution is possible, however, since the problem is not to calculate the impact force for a specific case of landing, but to determine the worst possible landing conditions in a given case. Of a certain number of take-offs and landings, one at least will encounter the worst landing conditions. The latter must be determined in actual flight tests. As shown below, the tests actually provide the required information, and it is expected that they will eventually show the best landing conditions corresponding to given seaways. Although the final solution of this problem must be effected by tests, we have attempted to determine the worst landing conditions on purely theoretical lines and to calculate the maximum landing impact. Figure 1 shows the assumed landing case. The seaway is diagrammatically represented by a trochoid and corresponds to seaway 2. The seaplane glides horizontally at the angle of attack of maximum lift. Under the worst conditions it strikes a wave head-on, as shown in Figure 1. The elasticity of the Heinkel monoplane used for the test was determined by vibration tests. The length of the colliding bottom portion and the velocity component of the seaplane normal to the bottom were scaled off from the drawing and used for the numerical calculation. The results are plotted in Figures 4 and 5 against the bottom or keel angle. The intermediate values for flat V bottoms are obtained by approximation in plotting a tangent to the curve of the sharp V bottom through the values for the flat bottom. The magnitude of these values agrees very well with that of the ordinary empirically determined load conditions (Fig. 6), except for the influence of the keel angle, which is interpreted more favorably by the

theory than by the load assumptions in Figure 7.

IV. Landing-Impact Tests

1. General observations

In the present case the tests serve the double purpose of

a) Checking the theory and improving it by experimental coefficients;

b) Determining the length of the colliding bottom portion for different seaways and landing maneuvers.

The three test methods are:

1. Physical-impact tests on ideal bodies, irrespective of technical problems;

2. Water-tank tests of hull and float scale models under conditions closely approaching those of reality;

3. Actual seaplane tests.

Physical tests are being made in Japan, and the first results are already available. Watanabe has made drop tests with cones having an angle of 160° at the Tokio Institute of Physical and Chemical Research. The impact force was determined by the piezo-electric method.* In the case of V bottoms, the theory is partially verified by these tests. The calculation, in which the flow about the rectangular plate of the above formula had to be replaced by the flow about a circular plate, was published in the Zeitschrift für Flugtechnik und Motorluftschiffahrt as a supplement to Watanabe's report.** The result is here briefly stated. Figure 8 shows Watanabe's test points and the theoretical curve. The slight difference is apparently due to the fact that the conditions of continuity were not fulfilled. The displacement by the submerged cone banks up the water on the sides, with an effect similar to increasing the keel angle (Fig. 9). The dash-line curve in Figure 8 was obtained by an empirical correction based on such assumptions.

*S. Watanabe, "Resistance of Impact on Water Surface." Scientific Papers of the Inst. of Phys. and Chem. Research, Feb. 20, 1930, Vol. 12, No. 226, Tokio.

**W. Pabst, "Vergleich zwischen theoretischer und experimenteller Ermittlung des Stosses eines auf die Wasseroberfläche auftreffenden Kegels," Z.F.M., 1930, p. 418.

Water-tank model tests are particularly suitable, because take-off resistances are also determined by them. Certain difficulties resulting from the laws of models are encountered in model impact tests. Inasmuch as the impact forces are of a higher order of magnitude than the take-off resistance, the wave-forming and frictional forces during the impact are smaller than the inertia forces and are therefore negligible. Froude's and Reynolds' laws of similarity can therefore be disregarded in applying the results of model tests to actual aircraft. Newton's law of similarity cannot be applied without restriction. As stated above, elasticity plays an important part in impacts. The problem therefore involves elastic forces in addition to inertia forces, so that Cauchy's law of similarity must be applied, according to which a satisfactory conversion from model to actual aircraft is possible only when both have the same Cauchy's number. It is very difficult, however, or even impossible, with small models, to obtain the requisite degree of elastic similarity between the model and the actual aircraft. Such tests are satisfactory only when they serve the purpose of a general study of the impact. The various factors, especially elasticity, must then be clearly defined, or the elasticity of the actual aircraft duplicated and in close conformity with Cauchy's law of similarity. Model tests, on the contrary, are well suited for sharp V-bottom hulls, which are less affected by elasticity. The restriction of the model tests does not affect the investigation of seaplane pitching and rolling motions in the seaway. Since the actual impacts are of very short duration, the momentum, which equals the time integral of the force, is rather small owing to its short period of action, in spite of the great impact force. It is much smaller than the momentum of the hydrodynamic and hydrostatic lifting forces resulting from the impact. This likewise accounts for the failure of impact measurements plotted from photographs of seaplane motions, or from model tests, since the quick but very small accelerations corresponding to the impact, are too small as compared with the slower but much greater accelerations due to bottom effects or buoyancy, to be recorded by the instruments. Besides, a double differentiation of the recorded values would always encounter difficulties.

These considerations led to the undertaking of full-size tests which, in addition to purely technical difficulties, present certain other disadvantages. Thus, in checking the validity of a theory, the effect of the seaway, landing speed, etc., are very difficult to determine, so that other factors, such as the keel angle, cannot be clearly defined. The tests described below show, however, that these disadvantages are not so great as feared, being largely offset by the advantages offered by the results of such tests for the further development of seaplane types and for the study of the theory of the landing impact, and which are not offered by any model or laboratory tests.

2. Apparatus

Full-size flight tests consist chiefly of float-bottom or hull-bottom pressure tests and elongation measurements of the float structure and of other structural members for the determination of the stresses and forces.* This involves the measurement of very quick and sudden motions. The problem is greatly complicated by the violent motions and accelerations of the whole seaplane and by the engine vibrations. The size and weight of the instruments must be greatly reduced, in order to increase the number of test points or stations. Much trouble is also caused by the chemical and mechanical effects of the spray.

These difficulties had to be overcome by a special test method, which, on account of its extensive applicability, has already been described by the writer.** According to this method, the elongation, proportional to the stress within the elastic limit of the material, is directly scratched by a diamond on glass in very fine lines which are measured microscopically. The detrimental bending vibrations of levers are thus avoided, the recording inertia considerably reduced and the sensitivity greatly increased (Fig. 10). The pressure measurements are made in a similar way. A flat box is attached to the bottom of the float or hull and a thin plate is soldered over its cut-out portion (Fig. 11). The deflection of the plate by the pressure is transmitted through a hole in the float bottom to the recording device inside of the float and scratched by a diamond on glass. The indications are practically unaffected by inertia. The natural vibration number of the instrument, in air, was 1500 Hertz, which would indicate approximately 1000 Hertz in water, so that, according to the well-known conditions, pressure vibrations of about 250 Hertz were recorded practically without error. Inasmuch as the observed frequencies were of the order of 75 to 100 Hertz, the pressure measurement was practically unaffected by inertia. The two instruments are shown in Figures 10 and 11. Figures 12-14 are microphotographs of the recorded diagrams. Further details are contained in the above-mentioned report.

3. Float-gear force measurements

The stresses in the float gear of a Heinkel monoplane were measured first, as a means of checking the theory and the calculation. The stresses can be divided, in the usual manner, into

*F. Seewald, "Über die Messung der Kräfte an Luftfahrzeugen. Z.F.M., 1928, p.474. (For translation, see N.A.C.A. Technical Memorandum No. 519.)

**W. Pabst, "Aufzeichnen schneller Schwingungen nach dem Ritzverfahren," V.D.I., 1929, p. 1629.

main and secondary stresses. The main stresses were produced in an ideal framework under the action of the impact forces. They were accompanied by secondary stresses, produced by moments at joints and welded points, and by vibrations in the struts. A complete picture of the stress distribution would require the testing of three or four marginal fibers of each strut, located at intervals of 90° about the strut axis. Such tests would not only yield the resultant forces and their moments in space during a take-off or landing, but also any additional stresses produced by moments on the supports and by vibrations of the struts. Such a complete test could not be made for lack of the requisite number of extensometers. The scope of the test had therefore to be greatly reduced which was made possible by using the seaplane "HE 9a" for the tests. The struts of this seaplane are made of rolled streamlined steel tubing and show no tendency to vibrate or collapse in the plane of their maximum width. The elongation in the forward marginal fiber was therefore assumed to be proportional to the strut force, which was actually confirmed by the tests. In view of the great scope of the problem, the determination of the secondary stresses due to strut vibration had to be foregone, notwithstanding their importance. Moreover, the test was confined to the determination of the vertical and horizontal components of one side only and the determination of the lateral impacts was therefore postponed.

Figure 15 shows the seaplane used for the tests, a Heinkel "HE 9a" monoplane, which was kindly furnished by the Travemünde experimental section of the German Society of Aircraft Constructors. The most important data regarding this seaplane are given in the appendix (3). Figure 16 shows the installation of the extensometers which, according to the problem, were mounted on all struts having both vertical and horizontal components. The advance of the recording glass plates was accomplished through flexible shafts by means of a water-tight electric motor mounted on top of the float. The motor was started from the observer's seat during take-off and landing maneuvers. The extensometers were wrapped in sailcloth. The wrapping was removed from the diagonal strut in Figure 16, which collapsed during the last test. Figure 25, which shows the rear attachment of the "HE 5" float, affords a better idea of the installation of the extensometers. The method of attachment has been recently improved. The very instructive bottom-pressure measurements had to be omitted in the present case, because the only available instrument could not be readily reinstalled in the float after it had become loose during a preliminary take-off. Attention is called instead to other bottom-pressure measurements on a similar seaplane, the "HE 5," which are described below. Three take-offs and three landings in different seaways, each with flat and V-bottom floats, were originally planned. This program could not, however, be fully carried out, due to damages sustained by the

float gear, so that only a small number of tests were made, two of which consisted of only one or two take-offs and landings.

The landings were made with idling engines. The seaplane was observed and filmed from an accompanying boat, while its landing speed was recorded from another boat by means of a camera. During the tests the weather was cloudy and the visibility poor, so that most of the landing pictures could not be interpreted. The same statement applies to the stereographs of the wave motion which were taken for the determination of the seaway. The stereoscopic method also proved unsatisfactory for other reasons, so that another method is being considered for future tests. The figures given in this report for the different seaways are based on naval practice. The wind velocity was recorded near the shore. The seaway and wind did not correspond. The wind was stronger than would correspond to the seaway, because the tests were made near the shore. The higher wind velocity was offset by the greater landing speed. The impact forces scaled off at different moments from the extensometer diagrams are given in the test results in the appendix. They are obtained as usual by the conversion of elongation to tension, tension to member stress and by the addition of the vertical and horizontal components of the member stresses for the front and rear joints and for the connecting member. The mean stresses and the force components in the individual struts are given for two tests - one landing and one take-off (Nos. 5 and 6 in the appendix). Figures 17 and 19 show the direction and point of application of the impact forces on the seaplane during a landing and take-off, and Figures 18 and 20 show their succession during the take-off and landing. Figure 12 is a microphotograph of the extensometer diagram, which was plotted on the forward fuselage strut during a landing.

According to the numerical tables and to Figures 17 and 19, the resultant force is often slightly inclined backward, while it is to be expected that the resultant will be perpendicular to the float bottom, since the water can exert no tangential forces other than the negligibly small frictional forces. It is still uncertain whether this is due to errors of measurement or interpretation, whether, perhaps, the tubes are not accurately rolled to the section assumed in the calculation or whether certain fixation moments are developed. It is indeed conceivable that, under the action of the impact, the deflection of the bottom may cause the float bulkheads to project as transverse edges, in which case the fluid pressure might also produce horizontal forces. This assumption is favored by the fact that most of the oblique resultants act directly in front of the bulkheads. Moreover, the slight elasticity of the bottom near the bulkheads increases the pressure at these points, so that the bottom usually gives way first in the neighborhood of a bulkhead (Fig. 21).

This problem may eventually be solved by avoiding the errors due to secondary stresses. It is hoped to accomplish this by a special float gear with ball joints and individually calibrated members, so as to eliminate errors due to fixation moments and to inaccurate cross sections.

Figure 22 shows the vertical forces in the float gear for different take-offs and landings and for different seaways, as plotted against the distance from the C.G. The resulting groups of points were delimited by curves which indicate the maximum vertical impacts for the corresponding seaways. It is particularly significant that the groups of points can be approximately limited toward the rear by straight lines passing through zero at the step and having roughly the same slope in the various series of tests with flat-bottom floats. According to theory, the c.p. of uniformly stiff bottoms of constant width is assumed, for reasons of symmetry, to be in the middle of the colliding bottom area or in the middle of the corresponding float length, forward of the step. Confusion must be avoided with the c.p. of planing float bottoms in the case of dynamic lift, when the accelerated water mass flows in from the front and is chiefly accelerated by the front end of the planing bottom. In this case, therefore, the c.p. lies quite far forward. The possible additional dynamic lift, due to the forward motion of the airplane, and the resulting slight forward shifting of the c.p. are neglected in the present case, especially since the position of the c.p. is slightly affected by differences in the bottom stiffness due to the frames and bulkheads. Figure 23 shows the seaplane with colliding bottom areas of different lengths, (a) and (b) in seaway 2 and (c) in a heavier seaway. The direction of the impact force in the neighborhood of the step depends on the length of the colliding portion of the bottom. This is no longer true when the colliding portion of the float is closer to the bow. The magnitude of the impact force depends likewise on the volume of the accelerated mass of water or on the length of the colliding portion of the bottom. According to Zeitschrift für Flugtechnik und Motorluftschiffahrt, 1930, page 220,

$$P_{max} = c_a \frac{M_1 M_2}{M_1 + M_2} .$$

A further approximation shows that M_2 is negligibly small as compared with M_1 for a small aspect ratio a/b. For very small aspect ratio $M_2 = C a^2 b$,

$$P_{max} = C' c_a a.$$

Theoretically, the increase of the impact force in front of the step is approximately linear for small aspect ratios of the col-

liding portion of the bottom. The slope of the straight line is independent of the seaway and is affected only by the landing speed and the angle of impact.

The possible length of the colliding portion of the bottom in the most unfavorable case depends on the seaway, as already mentioned. According to Figure 23 the length of the colliding portion of the bottom increases with the seaway. The resultant of the impact is then greater and located farther forward, as shown by the shifting of the maximum impact force (Fig. 22).

We shall now compare the calculation on page 223 of the Zeitschrift für Flugtechnik und Motorluftschiffahrt of 1930, with the test results. The calculated impact force on the fuselage is 6 G in seaway 2, while according to the test, it slightly exceeds 6 G in a seaway averaging 2. The agreement is therefore very good. According to the above considerations, the assumed length of the colliding bottom and angle of impact on which the theoretical calculation is based must be slightly improved. The length of the colliding bottom in Figure 22, which corresponds to the worst landing conditions, is approximately $a/2 = 72$ cm or $a = 144$ cm. The structure of the seaway seems, therefore, to have differed from the fully developed seaway, which may vary with the force of the wind and the place where the test is made. The larger bottom area shows that, for approximately the same impact force, the impact angle between water and float bottom, assumed to be 12°, must really have been smaller. According to a reversed calculation this angle should be about 10° for 90 km/h and $a = 1.5$ m. The angle varies with the landing maneuver and speed and the attitude of the seaplane. Besides, on shorter and steeper waves the maximum impact is shifted forward and the float bow is subjected to greater stresses. The best landing maneuver for any given seaway must be determined experimentally. A simple and easy method for the determination of the seaway, or at least of the wave height and length, is particularly desirable. In general, a thorough knowledge of seaways, especially of those of the North Sea and Baltic Sea, would be helpful with a view to improving the seaworthiness.

The values obtained for a V-bottom float are also plotted in Figure 22. Since, however, the waves were higher (seaways 2 to 3), the values, in spite of the V bottom, are greater than those for the flat-bottom float in seaway 2. Notwithstanding the varying test conditions, the effect of the V bottom is shown by the characteristic limiting line through the step. According to the above statements the slope of this line, for the same landing speed and angle, depends only on the shape of the float bottom. Under these conditions the effect of the keel angle on floats of equal width is expressed by the ratio between the tan-

gents of the angles of inclination of the limiting lines. In the present case, this bottom factor is approximately 80%, whereas the theoretical factor is 70% (Fig. 24). If the uncertainty of the above assumptions, due to the small number of test points and the interpolation of the theoretical calculation, be disregarded, the discrepancy can be attributed to the chines which, although neglected by the theory, undoubtedly increase the impact force. The small discrepancy between calculation and test is probably due to the wave along the inclined sides of the bottom on each side of the keel, the effect of which is similar to that produced by increasing the keel angle. A similar phenomenon was observed in comparing the theory with Watanabe's test results. The effect of the keel angle must have been assigned too much importance in the theory, since, even after the elimination of the chines, the actual values lie between the theoretical load assumptions and those of the D.V.L. A more accurate determination of the correction factors of the theoretical calculation would require further tests.

4. Further stress measurements

Several elongation diagrams are shown in connection with these float-gear force measurements. They were not obtained by a systematic investigation, but plotted during the first test of the extensometers. They make it possible to allow for the lateral impacts and the strut vibrations, which were not taken into consideration in the force measurements.

The lateral impacts, which tend to turn the float about its longitudinal axis, are converted, in Heinkel monoplanes, into bending moments in the float struts and in the forward and rear fuselage struts which are welded to the former. Figure 25 shows the manner of installation of an extensometer on the fuselage strut at the marginal fiber of this plane of flexure. Figure 26 shows an elongation diagram. It was plotted during the landing of a seaplane on sheltered water, but in a strong wind and consequently on rough water, so that the stresses were rather large. The diagram seems to be one of resonance vibrations produced by a quick succession of impacts of short waves. The frequencies of the diagram agree well with those observed in a vibration test. During a vibration test on a similar seaplane, an "HE 8," a torsional vibration of the float about its longitudinal axis developed at 820/min. = 13.7/sec., while the diagram shows a frequency of 12 to 13 per second. The great stresses even on sheltered water indicate that the admissible stresses are liable to be greatly exceeded on unsheltered water. Experience shows, however, that such is not necessarily the case. When the wave motion ceases to be in resonance with the float motion ow-

ing to the much longer period of the seaway, the great softness due to the relatively small vibration coefficients tends to reduce the impact force. The vertical impact in rough water may be cut down by reducing the stiffness of the float gear. This can be achieved by springs, which would facilitate landing on relatively smooth water with only short low waves. The danger of resonance vibrations may be further reduced by means of damping devices. The V bottom is usually much better suited for a reduction of the impact, when the take-off is not too unfavorably affected.

Figure 27 was plotted on a diagonal fuselage strut of an "HE 5" during a landing. Considerable stresses were also set up in this case. They may be due to the fact that bending vibrations were produced in the strut by stresses, whose period depended on the impact vibrations of the whole system, including the seaplane, floats and water. Such bending vibrations tend to cause premature buckling.

In order to use the strut material to the best advantage, the natural vibration numbers should be determined by tests, these being of great assistance in the determination of the landing impact forces, as shown by the good agreement between calculation and test. The usual test arrangement for the determination of wing vibration can be changed for the determination of landing impacts. The airplane may be suspended (by elastic springs, rubber cord, etc.) in such a manner that the bottom, over a certain length forward of the step, can be dipped in the water. The impact frequencies are then set up by inertia in accordance with the vibrating water mass, and the impact for a given bottom length is thus directly determined. It is then easier to discover whether individual struts are in resonance with the natural vibrations of the whole system, which can then be changed by increasing the inertia moment of the cross section.

Owing to its effect on the impact and to its dependence on the seaway the length of the colliding bottom affords a criterion for the safety of the landing impact. The statement of the bottom length which, at normal landing speed and unfavorable angle of impact (pulling up in level flight), allows the 0.02 yield limit of the weakest seaplane part (assumed breaking point) to be exceeded, renders it possible to estimate the heaviest seaway in which the seaplane can land and from which it can take off. Besides, the relative length of the colliding bottom, expressed in per cent of the length of the float portion forward of the step, shows the relative degree of safety of a seaplane as regards its landing impact. This method has the advantage of indicating the landing-impact characteristics of a seaplane independently of the seaway, of its structure and of the pilot's skill in landing the seaplane. It thus represents a sort of criterion for the safety of the landing impact.

5. Bottom-pressure measurements

The bottom-pressure measurements made last year were chiefly devoted to testing the instruments described above. The only apparatus available for this purpose was a bottom-pressure indicator. The device was mounted 35 cm forward of the step and 20 cm from the central line on the flat bottom of a wooden float of the "HE 5." Many take-offs and landings were made in the seaplane harbor and a few in seaways 1 to 2. Figure 13 is a diagram of the bottom pressures measured during a landing in seaway 1 to 2. It shows clearly the rapid pressure vibrations superposed at certain points over the slower pressure vibrations probably corresponding to the dynamic lift. The latter, due to their longer duration, affect the motion of the airplane much more than the greater but quicker pressure vibrations of the impact.

The maximum pressures were:

1. In the Travemünde seaplane harbor:
   while taking off, 1.0 to 1.35 kg/cm^2,
   in one case 1.6 kg/cm^2;
   while landing, 1.1 to 1.35 kg/cm^2,
   in two cases (leveled off high above the water)
   1.95 and 2.1 kg/cm^2.

2. In seaway 1 to 2:
   while taking off, 1.25 to 1.9 kg/cm^2;
   while landing, 1.45 to 1.75 kg/cm^2.

The frequency of the impacts was approximately 70-100 Hertz. The measured values agree fairly well with the theory. Calculation gave 1.8 kg/cm^2 and a frequency of 72/sec. in seaway 2. Any material increase in the measured pressures with increasing seaway is not to be expected, since the bottom pressures are only slightly affected by the area of the colliding bottom and hence by the seaway. A theoretical determination of the bottom pressures is therefore quite possible, but it must be remembered that the pressures on flat-bottom floats are materially affected by the elasticity of the bottom. Owing to the very irregular distribution of elasticity over the float bottom, the pressures are small at certain points and great at others as, for example, near the bulkheads. This is confirmed in practice by the fact that float bottoms usually break first in the neighborhood of the bulkheads. This is true only of flat and slightly V-shaped bottoms, but not of sharp V bottoms which are less affected by elasticity. The different degrees of elasticity of flat bottoms are shown by the frequency of the pressure diagram, which might also be a convenient way to obtain data on the elastic properties of various bottom types for future calculations.

Another, but less accurate method for the determination of impact forces on the bottom consists in plotting the deflections of the bottom planking under the action of pressure and calculating the corresponding bottom load by means of calibrated values. The latter can be obtained by comparing the bottom deflections produced by hydrostatic pressure while floating, planing and taking off. Figure 14 shows a diagram of the deflections of the bottom planking of a large flying boat during take-off which were plotted with the above-described extensometer and were not affected by inertia. The compound bottom vibrations are clearly shown in the diagram.

In this connection attention is called to the American measurements made by Thompson.* The instruments used were confined to the determination of maximum bottom pressures. The units operate on the principle of opposing the force due to water pressure on one end of a piston by a force due to the known pressure of a spring on the other end. When the water force exceeds the force of the spring, the piston moves a short distance and makes an electric contact which records the fact. It is thus possible to record two piston pressures, the one just exceeded and the other not yet reached, the actual bottom pressure lying between these two values. The theory was checked as far as possible by these tests.

The test values agree very well with the theoretical values. The speed component was the indicated velocity against the water multiplied by the sine of the angle of inclination. This is correct only for a horizontal flight path at the moment of landing. The colliding bottom length was taken from the above tests and reduced to the scale of the wave height. Thus, for a wave height of 40-45 cm, the speed is 76-89 km/h for a landing angle of 13^{o}, a fuselage acceleration of 1.4 to 2.8 g, and a bottom pressure of 0.34 to 0.69 kg/cm^2, while an acceleration of 2.5 g and a pressure between 0.51 and 0.7 kg/cm^2 were measured. The agreement between test and theory is quite satisfactory, and it is hoped that the load assumptions will eventually be replaced by calculations which will better satisfy the requirements of each particular case. Many tests are still required to complete the theory and to provide the experimental data for calculation. The landing impact is only one of the many seaworthiness problems (such as stability, drifting, maneuvering, and water hammering) awaiting experimental solution.

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*F. L. Thompson, "Water Pressure Distribution on a Twin-Float Seaplane." (N.A.C.A. Technical Report No. 328, 1929.)

V. Summary

The theory of the landing impact is briefly stated and the applicability of a previously suggested formula is extended. Theoretical considerations regarding impact measurements on models and actual seaplanes are followed by a brief description of the instruments used in actual flight tests. The report contains a description of the strength conditions and deals exhaustively with force measurements on the float gear of an "HE 9a" with flat-bottom and with V-bottom floats. The experimental data are given and compared with the theoretical results. In general, the numerical agreement is satisfactory, except for the influence of the keel angle, which is underestimated by the load assumptions of the D.V.L. and overestimated by the theory. Several calculations are corrected on the basis of the tests. Stress measurements on float gear struts, bottom-pressure measurements on an "HE 5" float and deflection measurements on the bottom of a flying boat are also mentioned in the report. The agreement between theory and practice is found to be good in the present tests, as well as in earlier American tests. With a view to further research on the problem of the landing impact, attention is called to the importance of seaway measurements and airplane vibration tests. Moreover, inertia coefficients are suggested for the development of landing-impact safety factors.

VI. Appendix

1. Calculation of the landing impact of a flat-bottom seaplane (Fig. 28)

Forces on the fuselage (mass M_1):

$$P_1 = c_a \sqrt{k\ M\ \varphi}; \qquad \varphi = \frac{\frac{e\ c}{s}}{2\ B\ \sqrt{A - B}}$$

$$A = \frac{1}{2}\left[c\ \frac{r + s}{r\ s} + e\ \frac{s + w}{s\ w}\right];$$

$$B = \frac{1}{2}\sqrt{\left(c\ \frac{r + c}{r\ c} - e\ \frac{s + w}{s\ w}\right)^2 + \frac{4 e\ c}{s^2}}\ .$$

Forces on the float (mass M_2):

$$P_2 = c_a \sqrt{k\ M}\ \psi \qquad \psi = \frac{e}{2\ B}\left(\frac{A + B - C}{\sqrt{A + B}}\right)$$

$$C = c\ \frac{r + s}{r\ s}$$

The bottom pressure is to be determined by P_2 and by the area of the colliding bottom.

General formula (from a single mass system):

$$P_{max} = c_a \sqrt{k\ M_1}\ \varphi; \quad \text{where} \quad \varphi = \sqrt{\frac{\omega}{1 + \omega}} \quad \text{and} \quad \omega = \frac{M_2}{M_1}$$

In these formulas,

M = mass of whole seaplane $M_1 + M_2$,

M_1 = mass of fuselage = $r\ M$,

M_2 = mass of float = $s\ M$,

M_3 = mass of water

$$= w\ M = \frac{\pi}{8}\ \rho \frac{a^2\ b^2}{\sqrt{a^2 + b^2}}\left(1 - 0.425\ \frac{a\ b}{a^2 + b^2}\right),$$

$k_1 = c\ k$ = elasticity between M_1 and M_2,

$k_2 = e\ k$ = elasticity between M_2 and M_3,

$k = \dfrac{k_1\ k_2}{k_1 + k_2}$ total elasticity between M_1 and M_3,

$c_a = \sin \alpha\ v_a$,

v_a = landing speed,

α = angle of impact,

$\left.\begin{array}{l} a = \text{length} \\ b = \text{width} \end{array}\right\}$ of colliding portion of bottom.

2. Calculation of landing impact of a seaplane with a sharp V bottom

The impact force P:

$$P = c_a^2 \tan \frac{\alpha}{2} \frac{C \rho a^2}{\left(1 + \frac{M_W}{M}\right)^3}$$

where $$C = 0.786\ e^{-0.227 \frac{a}{b}}$$

and $$M_W = \frac{\pi}{8} \rho \frac{a^2 b^2}{\sqrt{a^2 + b^2}} \left(1 - 0.425 \frac{a b}{a^2 + b^2}\right)$$

for single-float and single-hull seaplanes;

$$C = 1.572\ e^{-0.227 \frac{a}{b}}$$

and $$M_W = \frac{\pi}{4} \rho \frac{a^2 b^2}{\sqrt{a^2 + b^2}} \left(1 - 0.425 \frac{a b}{a^2 + b^2}\right)$$

for twin-float and twin-hull seaplanes,

and

a = the colliding bottom length,
b = the width of float or hull,
α = angle of V or keel angle,
c_a = speed component normal to the water,
M = seaplane mass,
ρ = density of the water.

The maximum impact force may be produced by wide hulls before complete immersion of the V bottom, and hence before the maximum bottom width is reached, which must be governed by the introduction of different values for b. In this case the maximum impact force is substituted for the impact force as determined by the introduction of the hull width b. The impact forces on flat V-bottom hulls or floats are determined from the data for sharp V bottoms and flat bottoms.

3. Characteristics of the experimental seaplane, a Heinkel monoplane, "HE 9a" (Fig. 5)

Seaplane

Total weight .... $G = 3000$ kg

Moment of inertia about spar axis........... $\Theta_F = 1000$ kgms^2,

Wing loading................ $G/F = 63.2$ kg/m^2

Power loading .... $G/N = 4.25$ kg/hp,

Landing speed .... V = 80 tp 90 km/h

Float:

a) flat,

b) with a keel angle of 161°.

Capacity: a) and b) J_s = each float 3000 to 1

Weight a) $G_s = 143.0$ kg

Weight b) $G_s = 147.2$ kg

Moment of inertia about the transverse axis a) $\Theta_s = 48.9$ kg/ms^2

Moment of inertia about the transverse axis b) $\Theta_s = 47.6$ kgms^2

Flotation gear:

Material: Streamlined steel tubing,

Breaking strength 48 kg/mm^2, from data supplied by manufacturers.

4. Numerical Values of the Test Results

A. Tests with Flat Bottom Floats, November 28, 1929.
Pilot, Roth.

Table I: First position. Place: Lübeck Bay, opposite Brodtèn.

Wind: 6 m/s, in gusts up to 9 m/s south.
Seaway: slightly exceeding 1; Direction: same as wind.

(a) 1. Landing Landing speed: 100 km/h

No.		1	2	3	4	5	6	7	8
Time after first contact with water	s	0.3	0.8	2.5	2.9	3.5	4.0	4.45	5.2
Vertical forces forward	kg	2670	4520	1160	2180	3110	2860	2520	3200
Vertical forces aft	kg	3740	2200	1560	2330	1610	950	1220	1350
Total vertical forces	kg	6410	6720	2720	4510	4720	3810	3740	4550
Horizontal forces	kg	- 70	1315	25	55	860	745	585	845
Distance from C.G.	m	0.13	0.74	0.15	0.28	0.71	0.93	0.75	0.82

(The pressures are positive)

(b) 1. Take-off Take-off time: 9 seconds

No.		1	2	3	4	5	6	7	8
Time after opening throttle	s	2.8	5.4	7.5	7.8	8.8	9.2	9.9	10.9
Vertical forces forward	kg	1360	1020	2350	2520	3930	1840	1840	2520
Vertical forces aft	kg	85	840	2330	1070	1540	1570	1940	2200
Total vertical forces	kg	1275	1860	4680	3590	5470	3410	3780	4720
Horizontal forces	kg	305	40	325	655	900	-125	215	- 70
Distance from C.G.	m	1.39	0.45	0.32	0.82	0.85	0.43	0.30	0.41

4. Numerical Values of the Test Results

A. Tests with Flat-Bottom Floats, November 28, 1929.
Pilot, Roth.

Table I: First position. Place: Lübeck Bay, opposite Brodten.

Wind: 6 m/s, in gusts up to 9 m/s south.
Seaway: slightly exceeding 1; Direction: same as wind.

(c) 2. Landing — Landing speed: 100 km/h

No.		1	2	3	4	5	6	7	8	9
Time after first contact with water	s	0	1.6	2.2	2.9	3.4	4.0	4.4	6.2	7.3
Vertical forces forward	kg	-535	4660	2670	1840	1840	2010	1840	2520	3490
Vertical forces aft	kg	1165	2670	1210	2980	2310	1770	1135	1505	2875
Total vertical forces	kg	630	7330	3880	4820	4150	3780	2975	4025	6365
Horizontal forces	kg	5	735	600	- 40	30	235	390	740	450
Distance from C.G.	m	-2.87	0.66	0.78	0.05	0.20	0.41	0.62	0.90	0.45

(The measured stresses are shown in Table II. Figure 5 shows the resultant forces on the flotation gear, and Figure 7 the time curve while landing.)

(d) 2. Take-off — Take-off time: 11.7 seconds

No.		1	2	3	4	5	6	7	8
Time after opening throttle	s	2.45	3.20	5.95	7.40	8.85	10.35	11.2	11.7
Vertical forces forward	kg	850	850	4370	3200	2525	2865	3155	
Vertical forces aft	kg	- 30	-160	3120	1165	1800	1820	4040	
Total vertical forces	kg	820	690	7490	4365	4325	4685	7195	
Horizontal forces	kg	310	300	355	660	- 60	320	370	
Distance from C.G.	m	2.41	2.09	0.53	0.89	0.53	0.60	0.18	

4. Numerical Values of the Test Results

A. Tests with Flat-Bottom Floats, November 28, 1929.
Pilot, Roth.

Table I: First position. Place: Lübeck Bay, opposite Brodten
Wind: 6 m/s, in gusts up to 9 m/s south
Seaway: slightly exceeding 1; Direction: same as wind.

(e) 3. Landing

No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time after first contact with water	s	0.1	0.9	1.51	2.30	2.65	3.2	3.75	4.2	6.45	6.7	8.45	8.8	9.05	10.3
Vertical forces forward	kg	3410	3490	2670	3410	2810	3410	3210	2840	4465	3010	2695	3350	3180	3010
Vertical forces aft	kg	1850	3900	3080	2260	1720	680	1865	2400	1850	1740	1040	1680	2330	785
Total vertical forces	kg	5260	7390	5750	5670	4530	5050	3890	4705	6865	4750	3735	5030	5510	3790
Horizontal forces	kg	- 65	345	50	680	535	645	370	370	670	375	840	595	540	730
Distance from C.G.	m	0.69	0.26	0.24	0.57	0.62	0.75	1.11	0.58	0.69	0.65	0.86	0.73	0.50	1.03

(f) 3. Take-off Take-off time: 10.1 seconds

No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time after opening throttle	s	3.1	3.6	4.2	4.6	5.05	6.1	6.75	6.75	7.15	7.7	8.05	8.6	9.15	10.1
Vertical forces forward	kg	2345	2345	2600	1955	3495	1785	1820	1845	2125	3350	1675	2330	4465	
Vertical forces aft	kg	840	995	890	1180	870	940	450	1576	1170	1765	2590	1820	4510	
Total vertical forces	kg	3185	3340	3490	3135	4365	2725	2270	3415	3295	5115	4265	4150	8975	
Horizontal forces	kg	260	60	330	90	668	60	- 10	170	915	225	- 50	90	600	
Distance from C.G.	m	0.90	0.82	0.92	0.63	1.05	0.70	1.05	0.43	0.68	0.70	0.07	0.50	0.33	

(The stresses and forces in each strut are given in the appendix (6), while Figure 6 shows the distribution of the forces about the flotation gear, and Figure 8 the time diagram of the impacts.)

Table II: Second position. Place: Lübeck Bay, Pelzerhaken
Wind: 7 m/s, in squalls up to 10 m/s south
Seaway: nearly 2, parallel with wind

(a) 1. Landing

No.		1	2	3	4	5	6	7	8	9
Time after first contact with water	s	2.35	2.65	3.05	3.35	3.70	4.10	4.60	5.50	6.0
Vertical forces forward	kg	1250	1440	2450	1710	1480	2900	3410	2815	3980
Vertical forces aft	kg	2270	2615	3155	2980	2185	1680	3915	1510	1655
Total vertical forces	kg	3520	4055	5605	4690	3665	4580	7325	4325	5635
Horizontal forces	kg	65	625	185	-175	- 60	595	475	15	815
Distance from C.G.	m	-0.02	-0.02	0.18	0	0.11	0.65	0.24	0.69	0.82

(a) 1. Landing

No.		10	11	12	13	14	15	16	17	18
Time after first contact with water	s	7.75	7.85	8.20	9.55	9.65	10.8	11.8	12.3	12.8
Vertical forces forward	kg	5090	5090	2610	4225	4225	4610	3720	3410	5100
Vertical forces aft	kg	1585	4300	3650	-120	4215	1000	1410	1375	855
Total vertical forces	kg	6675	9390	6260	4105	8440	5610	5130	4785	5955
Horizontal forces	kg	380	555	260	95	550	675	590	180	1110
Distance from C.G.	m	0.96	0.43	0.13	1.60	0.32	1.10	0.87	0.84	1.19

Table II: Second position. Place: Lübeck Bay, Pelzerhaken
Wind: 7 m/s, in squalls up to 10 m/s south
Seaway: nearly 2, parallel with wind

(b) 1. Take-off

No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time after opening throttle	s	2.65	4.9	5.4	6.8	6.9	8.3	9.5	10.5	10.9	11.4	12.1	12.4	14.2	15.2
Vertical forces forward	kg	1150	2550	1870	3495	5000	4805	5630	2960	2185	2865	2790	3580	3980	2475
Vertical forces aft	kg	45	2750	210	1790	4360	3910	3500	1565	1770	240	3335	2335	4115	3335
Total vertical forces	kg	1195	5300	2080	5285	9360	8715	9130	4525	3955	3105	6125	5915	8095	5810
Horizontal forces	kg	45	-1715	75	255	-1700	-1970	950	535	335	215	475	-175	230	-145
Distance from C.G.	m	1.44	0.28	1.29	0.72	0.41	0.45	0.61	0.70	0.46	0.76	0.22	0.58	0.30	0.15

(During the last take-off the starboard float sprang aleak on the outer side of the step. This resulted in occasional strong forward horizontal forces on the tested port side of the float gear (columns 5 and 6). An explanation is afforded by the fact that the port side was deflected about the vertical axis under the action of the torsional impulses of the starboard float due to the leak. These phenomena ceased at higher speeds, at which the damaged float was relieved by the aileron moments. The crack in the float bottom was probably started during the first landing, while the actual leak began during the next take-off. The tests with flat-bottom floats were then discontinued.)

B. V-bottom float

Place: Lübeck Bay, opposite Brodten.
Wind: 8 m/s, in gusts up to 13 m/s
Direction: southwest. Seaway: 2 to 3, parallel with the wind.

(a) Landing

No.		1	2	3	4	5	6	7	8	9	10	11	12	13
Time after first contact with water	s	0	1.36	2.82	3.31	3.76	4.50	5.10	6.13	6.36	6.78	7.50	7.88	9.13
Vertical forces forward	kg		2960	5420	4400	6230	4805	2470	3300	3010	3930	3070	2730	3300
Vertical forces aft	kg		1945	50	435	1895	590	1735	1105	735	50	-385	1055	740
Total vertical forces	kg		4905	5470	4835	8125	5395	4205	4405	3745	3980	2785	3785	4040
Horizontal forces	kg		845	2245	570	760	1480	705	-260	455	1350	425	480	795
Distance from C.G.	m		0.58	1.50	1.31	0.97	1.27	0.54	5.93	1.06	1.50	1.78	0.86	1.09

(Column 3 shows a strong horizontal force in front of the bulkhead, at the forward attachment point of the float. It seems as though the crack, noticed after the second take-off, had already been started. Column 6 shows likewise a strong horizontal force in front of the bulkhead at the forward attachment point of the float.)

Table II: Second position. Place: Lübeck Bay, opposite Brodten

B. V-bottom float — Wind: 8 m/s, in gusts up to 13 m/s

Direction: southwest. Seaway: 2 to 3, parallel with the wind.

(b) 1. Take-off

No.		1	2	3	4	5	6	7	8	9
Time after opening throttle	s	6.3	6.7	8.1	9.0	9.38	10.3	11.3	11.8	16.7
Vertical forces forward	kg	5090	8480	3300	7120	3060	6120	2935	5870	29
Vertical forces aft	kg	290	1350	3185	2280	2290	1155	270	3940	
Total vertical forces	kg	5380	9830	6485	9400	5350	7275	3205	9810	
Horizontal forces	kg	2385	3550	875	2000	520	1920	440	1185	
Distances from C.G.	m	1.40	1.20	0.35	0.95	0.97	1.15	1.51	0.57	

(In this case also, strong horizontal stresses were developed, when the impact was exerted on the subsequently discovered crack in the bottom. After the take-off, no water was observed to flow from the float by the occupants of the accompanying boat. The crack near the bulkhead may not have been completely developed, so that the water which had penetrated into the float escaped slowly and could not be distinguished from the water dripping from without.)

(c) 2. Landing

No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time after first contact with water	s	0	1.47	2.98	3.65	4.33	4.67	5.08	6.09	6.55	7.03	7.45	7.92	8.85	12.1
Vertical forces forward	kg	-565	2960	2490	4270	2380	2490	4080	3590	3275	2450	2620	3870	7130	2960
Vertical forces aft	kg	1590	2865	3280	775	2145	1060	786	3140	1950	2435	- 10	1235	1290	240
Total vertical forces	kg	1025	5825	5770	5045	4525	3550	4860	6730	5225	4885	2620	5105	8420	3200
Horizontal forces	kg	85	730	365	1400	720	255	1540	1030	840	655	1900	770	3115	730
Distance from C.G.	m	-3.9	0.35	0.17	1.16	0.39	0.81	1.14	0.41	0.63	0.33	1.54	0.95	1.16	1.35

(Here also strong horizontal stresses were developed when the bottom collided in front.)

Table II: Second position. Place: Lübeck Bay, opposite Brodten.
Wind: 8 m/s, in gusts up to 13 m/s
Direction: southwest. Seaway: 2 to 3, parallel with the wind.

B. V-bottom float

(d) Take-off Take-off time: 14 seconds

No.		1	2	3	4	5	6	7	8	9
Time after opening throttle	s	5.25	6.39	7.10	7.38	8.86	9.30	10.2	11.8	13.5
Vertical forces forward	kg	2960	2620	3700	2730	3470	4250	4760	3000	2765
Vertical forces aft	kg	2455	830	510	2560	445	+1325	375	1925	2720
Total vertical forces	kg	5415	3450	4210	5270	3915	5575	5135	5155	5485
Horizontal forces	kg	100	1395	1735	100	570	810	1410	45	580
Distance from C.G.	m	0.44	0.93	1.24	0.36	1.26	0.96	1.35	0.63	0.34

(In this case also, strong horizontal stresses were developed, when the bottom collided at the forward attachment point. Much water flowed from the float after the take-off. The tests were then discontinued. The damaged float is shown in Figure 10. Another test was made subsequently in a heavier seaway. The diagonal fuselage strut collapsed, with the result that the extensometer mounted on this strut was damaged. The edges of two other extensometers slipped during drift-anchor maneuvers. Therefore the results of this test could not be utilized.)

5. Stresses and Forces in the Flotation Gear of an "HE 9a" with Flat-Bottom Wooden Floats While Landing in Seaway 1

Second landing in position 1, November 28, 1929

			1	2	3	4	5	6	7	8	9
Abscissa			0	32	45	59	68	81	89	125	149
Time			0	1.6	2.2	2.9	3.4	4.0	4.4	6.2	7.3
Forward	σ	kg/cm^2	-200	1200	700	500	500	550	500	700	900
fuselage	P_V	kg	-680	4080	2380	1700	1700	1870	1700	2380	3060
strut	P_H	kg	-360	2150	1250	900	900	980	900	1250	1620
Rear	σ	kg/cm^2	210	- 350	-200	150	150	-100	- 50	- 50	400
fuselage	P_V	kg	600	-1000	-570	430	430	-280	-145	-145	115
strut	P_H	kg	40	- 65	- 40	30	30	- 20	- 10	- 10	80
Diagonal	σ	kg/cm^2	-180	400	200	300	300	200	100	150	450
fuselage	P_V	kg	-415	920	460	690	690	460	230	320	1040
strut	P_H	kg	465	-1030	-500	-780	-780	-520	-260	-390	-1160
Forward	σ	kg/cm^2	50	200	100	50	50	50	50	50	150
wing	P_V	kg	145	580	290	140	140	140	140	140	430
strut	P_H	kg	105	420	210	105	105	105	105	105	320
Rear	σ	kg/cm^2	220	600	300	500	300	400	200	350	400
wing	P_V	kg	595	1600	810	1350	810	1080	540	950	1080
strut	P_H	kg	40	110	55	90	55	70	35	65	70
Diagonal	σ	kg/cm^2	150	450	200	200	150	200	200	150	250
wing	P_V	kg	385	1150	510	510	380	510	510	380	640
strut	P_H	kg	-285	-850	-380	-380	-280	-380	-380	-280	-480
Σ P_V forward		kg	-535	4660	2670	1840	1840	2010	1840	2520	3490
Σ P_V aft		kg	1165	2670	1210	2980	2310	1770	1135	1505	2875
Σ P_V		kg	630	7330	3880	4820	4150	3780	2975	4025	6365
Σ P_H		kg	5	735	600	- 40	30	235	390	740	450
Distance a		m	-2.87	0.66	0.78	0.05	0.20	0.41	0.62	0.90	0.45

6. Stresses and Forces in the Flotation Gear of an "HE 9a" with Flat-Bottom Wooden Floats While Taking Off in Seaway 1

Third take-off in position 1, November 28, 1929

			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Abscissa			62	72	84	93	101	109	122	135	143	154	161	172	183	201
Time			3.1	3.6	4.2	4.6	5.05	6.1	6.75	6.75	7.15	7.7	8.05	8.6	9.15	10.1
Forward	σ	kg/cm^2	650	650	700	550	900	500	450	500	600	900	450	600	1100	
fuselage	P_V	kg	2200	2200	2380	1870	3060	1700	1530	1700	2040	3060	1530	2040	3740	
strut	P_H	kg	1160	1160	1250	980	1600	895	805	895	1070	1610	805	1080	1970	
Rear	σ	kg/cm^2	-200	-200	-250	-150	-400	-200	-150	50	±100	-350	200	-200	400	
fuselage	P_V	kg	-570	-570	-715	-430	-1150	-570	-430	145	±285	-1000	570	-570	1140	
strut	P_H	kg	- 40	- 40	- 50	- 30	- 75	- 40	- 30	10	± 20	- 65	40	- 40	75	
Diagonal	σ	kg/cm^2	250	350	300	300	300	200	250	250	200	400	300	350	500	
fuselage	P_V	kg	575	780	690	690	690	460	575	575	460	920	690	800	1150	
strut	P_H	kg	-645	-900	-675	-675	-675	-515	-645	-645	-515	-1030	-775	-850	-1290	
Forward	σ	kg/cm^2	50	50	75	30	150	30	100	50	30	100	50	100	250	
wing	P_V	kg	145	145	220	85	435	85	290	145	85	290	145	290	725	
strut	P_H	kg	105	105	160	65	310	65	210	105	65	210	105	210	525	
Rear	σ	kg/cm^2	120	150	150	200	230	200	200	200	180	400	350	400	450	
wing	P_V	kg	325	405	405	540	620	540	540	540	485	1080	950	1080	1200	
strut	P_H	kg	20	25	25	35	40	35	35	35	30	70	60	70	80	
Diagonal	σ	kg/cm^2	200	150	200	150	280	200	150	120	200	300	150	200	400	
wing	P_V	kg	510	380	510	380	710	510	380	310	510	765	380	510	1020	
strut	P_H	kg	-380	-285	-380	-285	-532	-380	-385	-230	-380	-570	-285	-380	-760	
Σ P_V forward		kg	2345	2345	2600	1955	3495	1785	1820	1845	2125	3350	1675	2330	4465	
Σ P_V aft		kg	840	995	890	1180	870	940	450	1576	1170	1765	2590	1820	4510	
Σ P_V		kg	3185	3340	3490	3135	4365	2725	2270	3415	3295	5115	4265	4150	8975	
Σ P_H		kg	260	60	330	90	668	60	- 10	170	915	225	- 50	90	600	
Distance a		m	0.90	0.82	0.92	0.63	1.05	0.70	1.05	0.43	0.68	0.70	0.07	0.50	0.33	

Translation by National Advisory Committee for Aeronautics.

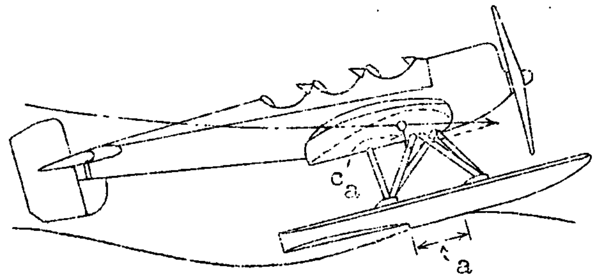

Fig. 1 Seaplane landing in seaway 2

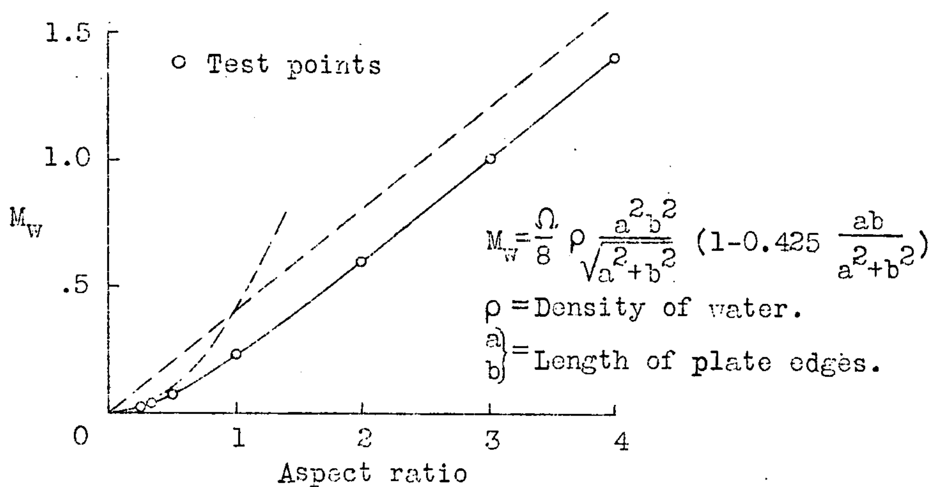

Fig. 2 The accelerated water mass of rectangular plates in a one-sided flow.

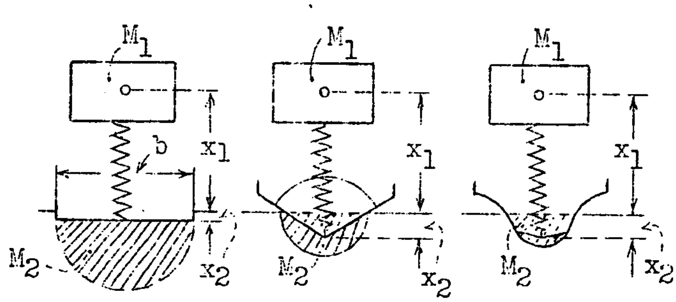

Fig. 3 Systems consisting of seaplane and water mass.

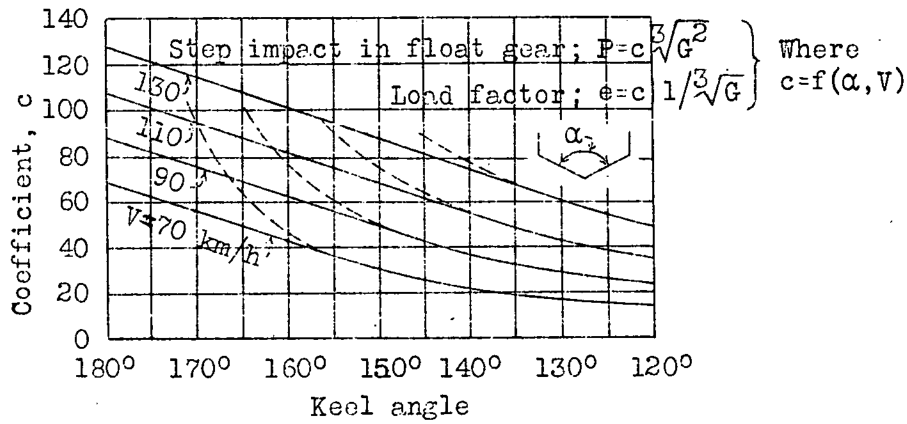

Fig. 4 Landing impacts of twin-float seaplanes of Heinkel monoplane type (theoretical).

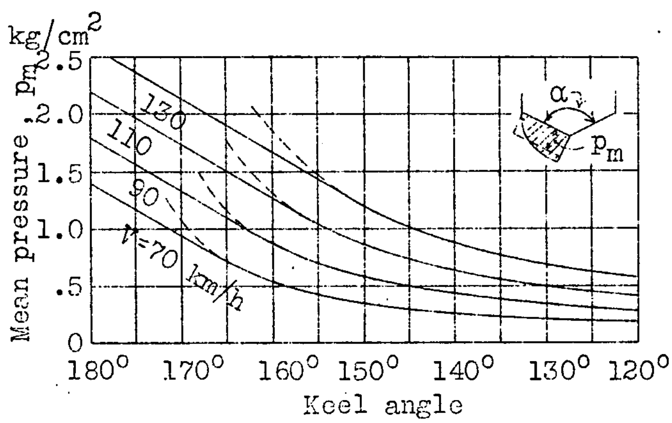

Fig. 5 Bottom pressures at step of twin-float seaplanes of Heinkel monoplane type (theoretical) $p_m = f(\alpha)$.

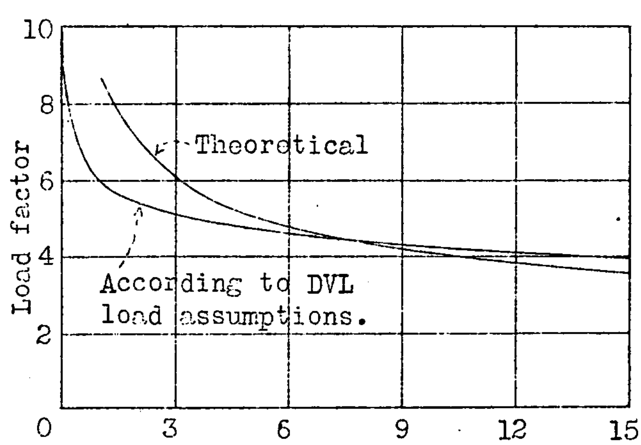

Fig. 6 Load factor plotted against total weight of similar seaplanes.

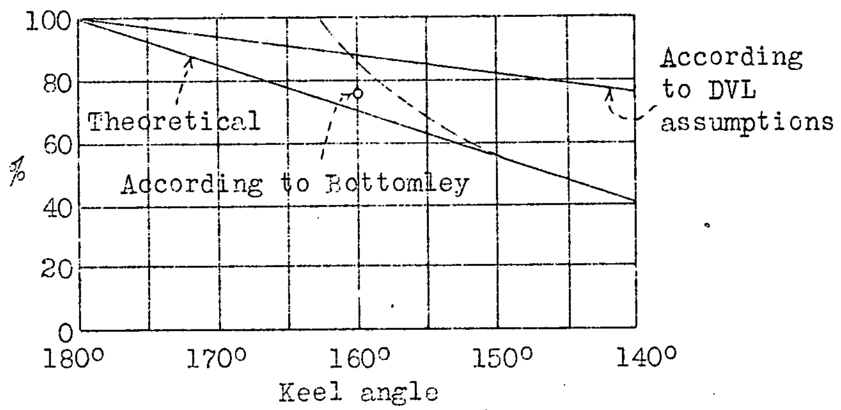

Fig. 7 Impact force plotted against keel angle.

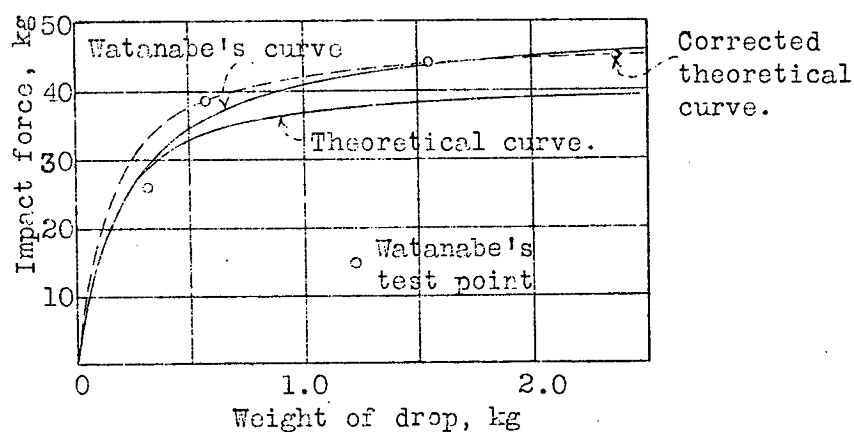

Fig. 8 Comparison of theoretical curves with the one obtained by Watanabe.

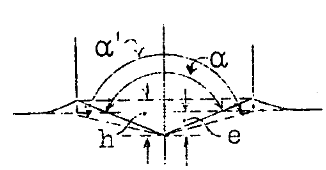

Fig. 9 Water rise about submerged cone.

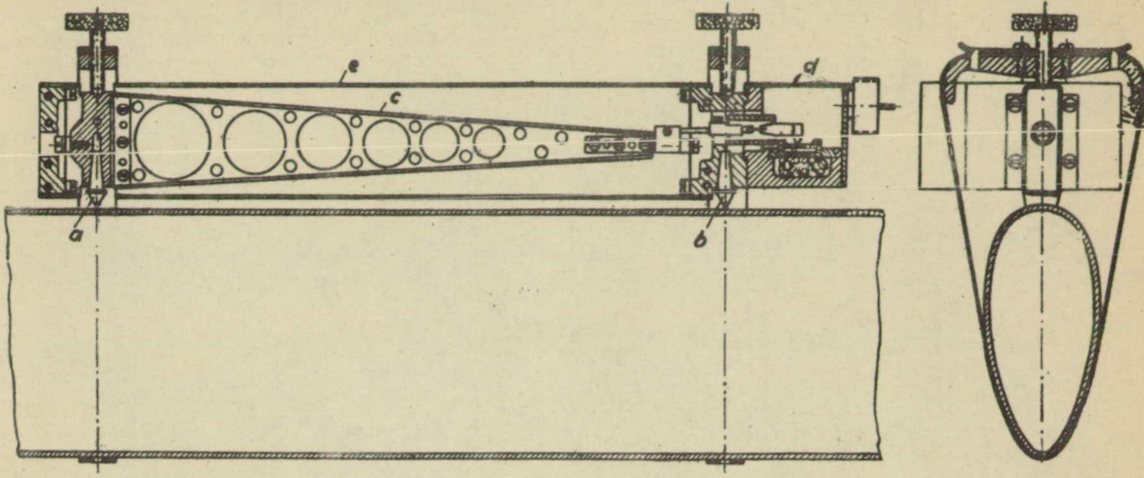

Fig. 10 Scratch-recording extensometer

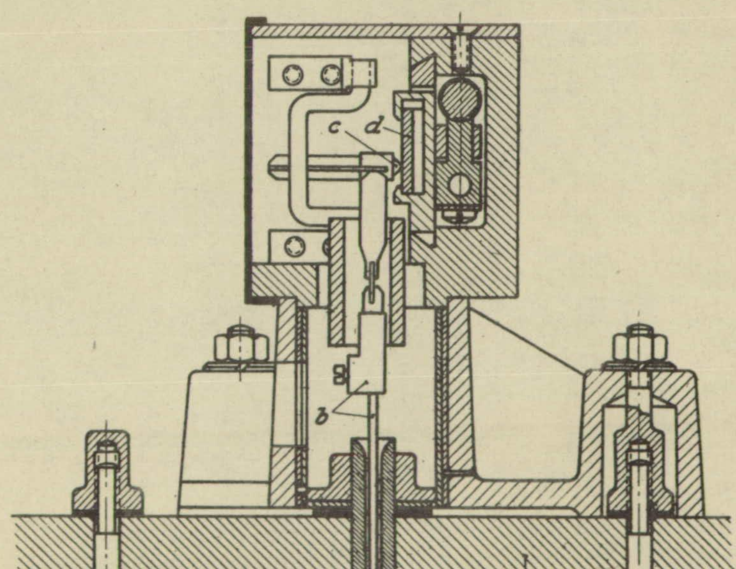

Fig. 11 Bottom pressure gauge.

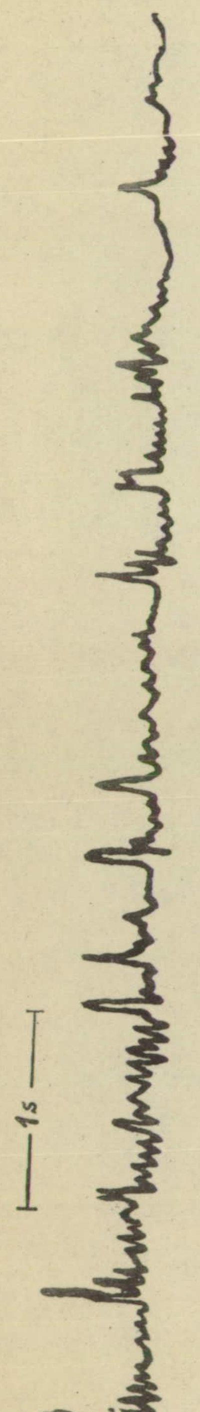

Fig. 12 Microphotograph of an elongation scratch diagram, measured on the forward fuselage strut of an HE 9a seaplane landing in seaway 2 to 3.

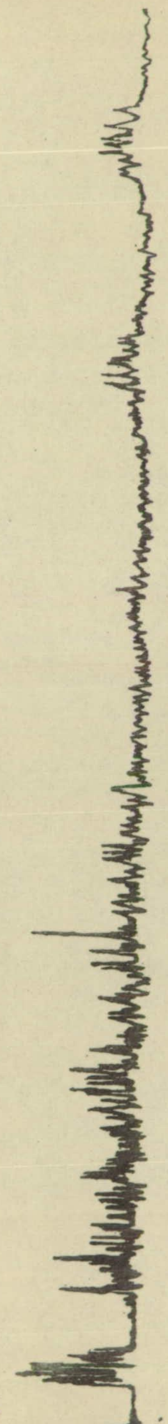

Fig. 13 Microphotograph of a bottom-pressure scratch diagram, measured on a flat-bottom wooden float of an HE 5 seaplane while landing in seaway 1 to 2.

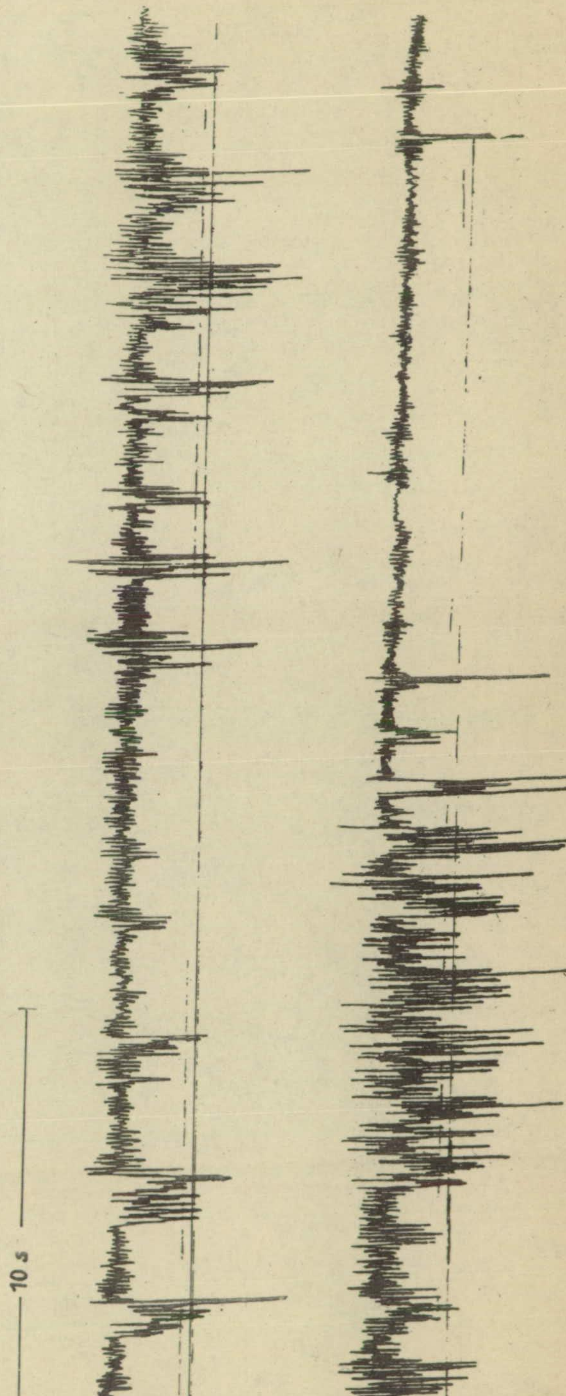

Fig. 14 Microphotograph of a bending deflection scratch diagram, measured on the bottom planking of a flying boat during take-off.

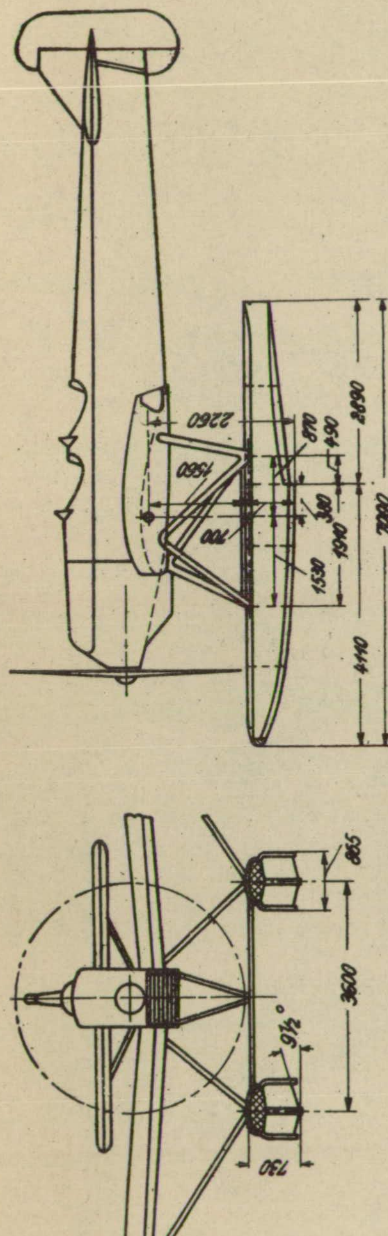

Fig. 15 The test seaplane, a Heinkel HE 9a monoplane

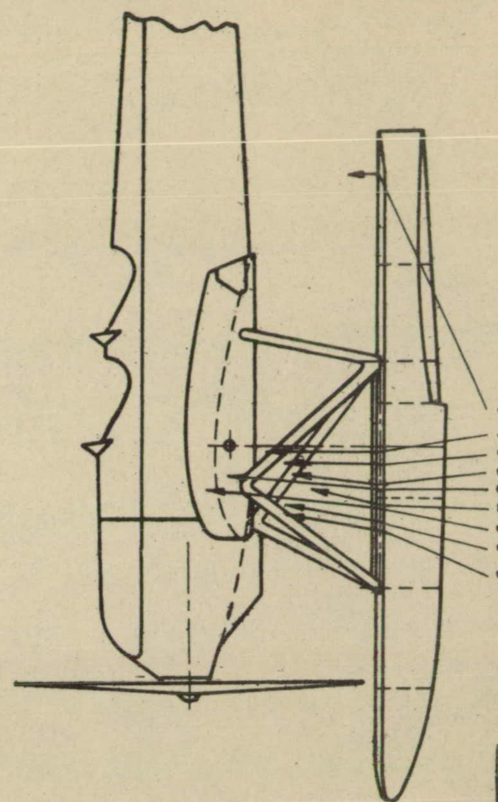

Fig. 19 Magnitude, direction and point of application of impact forces in floatation gear while landing.

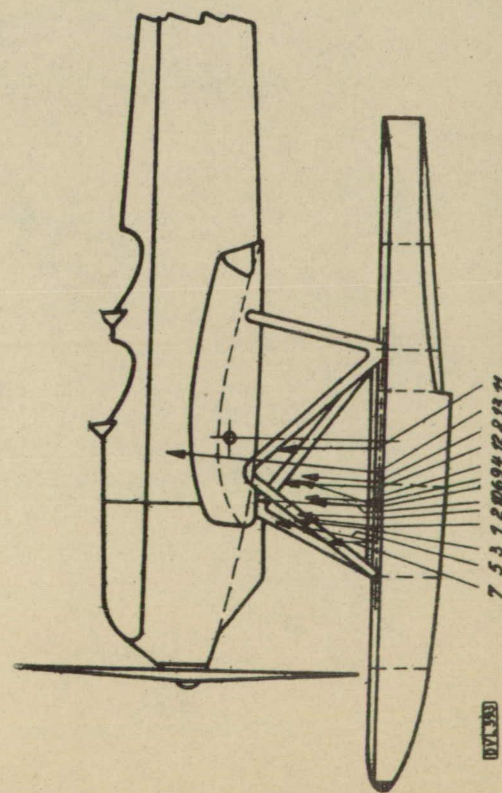

Fig. 17 Magnitude, direction and point of application of impact forces in floatation gear during take-off.

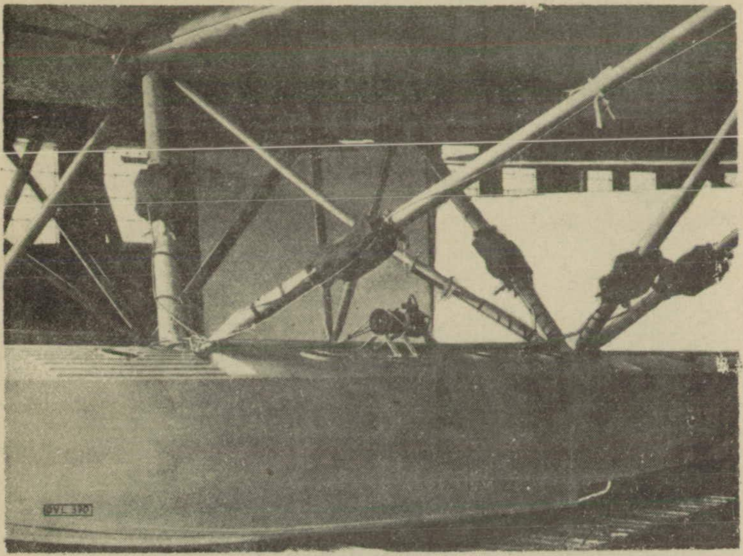

Fig.16

Installation of extensometers on flotation gear of HE 9a.

Fig.21

Crack in float bottom near bulkhead.

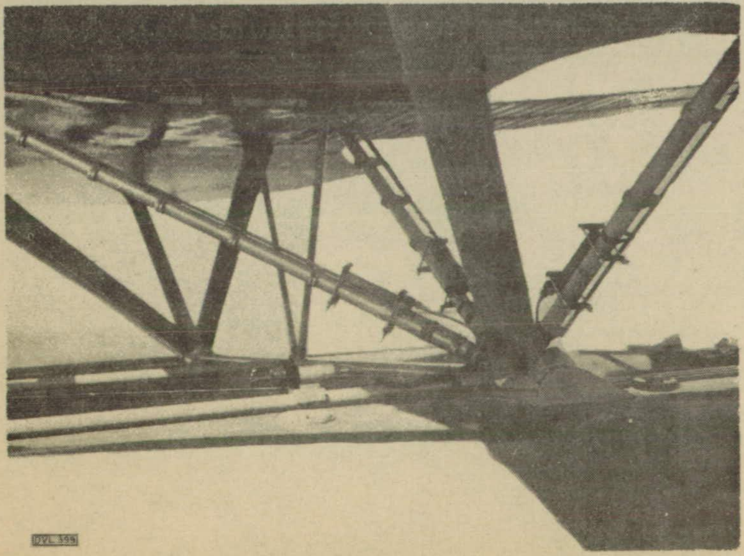

Fig.25

Installation of extensometers on flotation gear of HE 5.

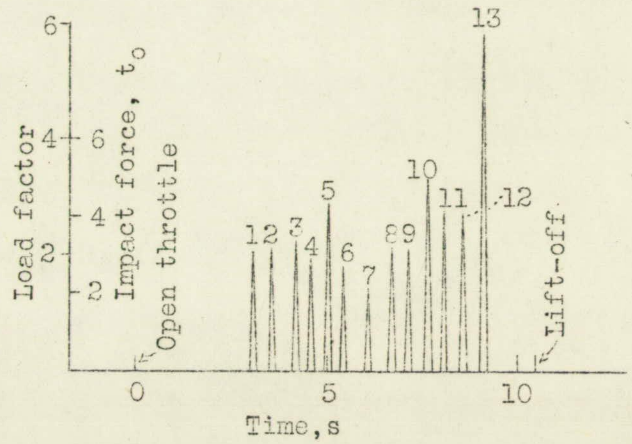

Fig. 18 Magnitude and time diagram of impact forces in floatation gear during take-off.

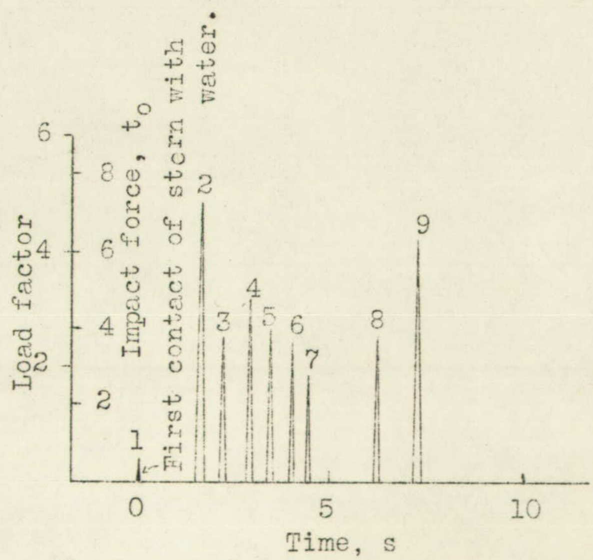

Fig. 20 Magnitude and time diagram of impact forces in floatation gear while landing.

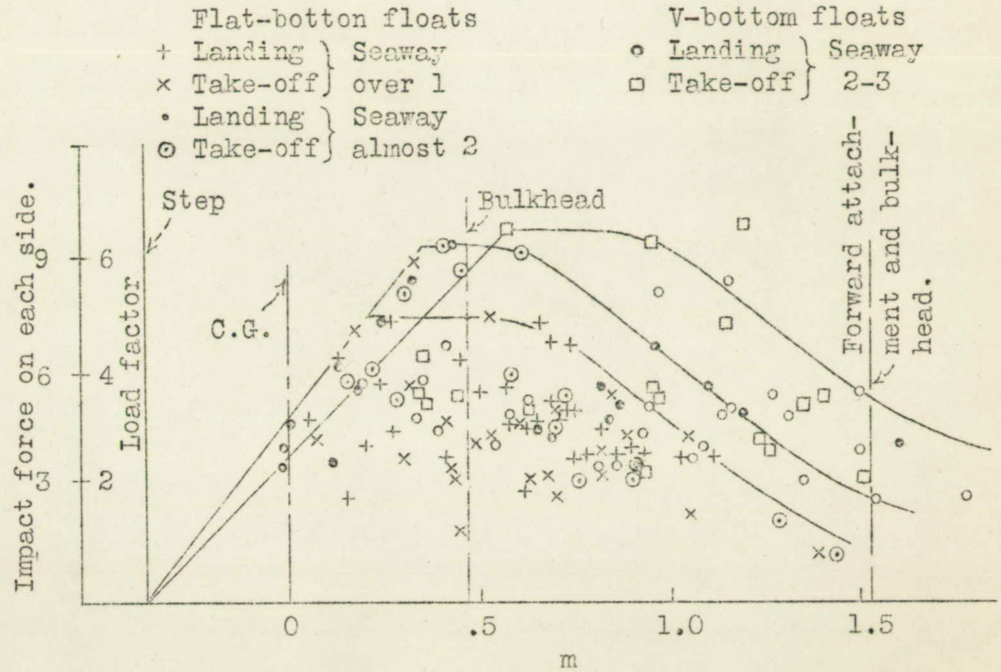

Fig. 22 Vertical forces in floatation gear during various take-offs and landings, plotted against distance forward of C.G.

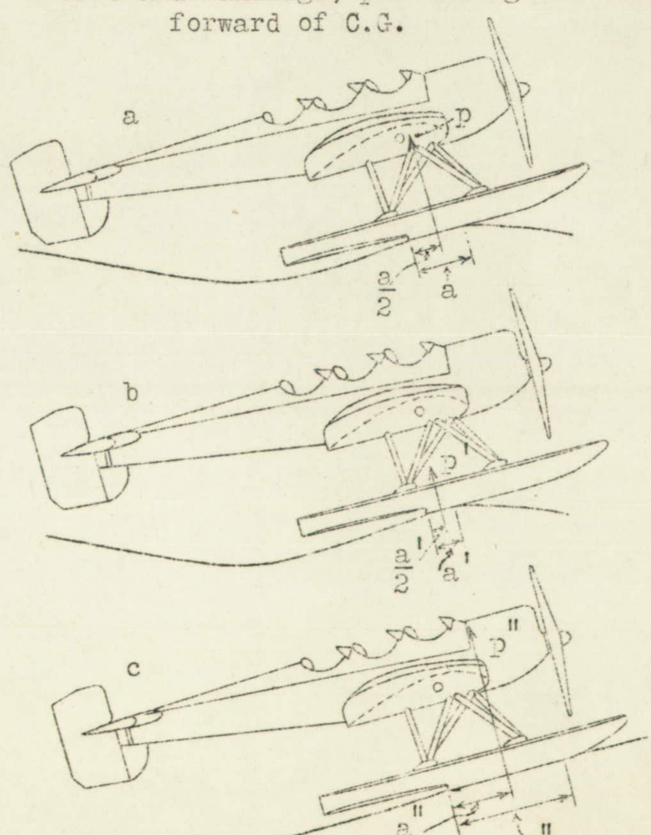

Fig. 23 Seaplane with different colliding bottom lengths.

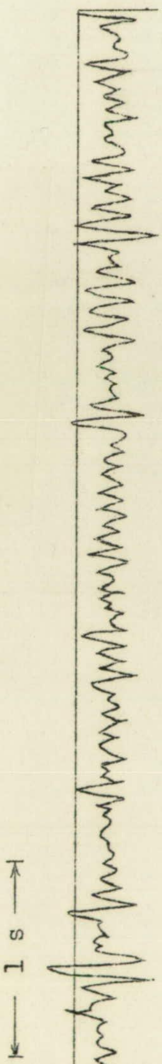

Fig. 26 Microphotograph of a scratched elongation diagram, plotted at rear fuselage strut of an HE 5

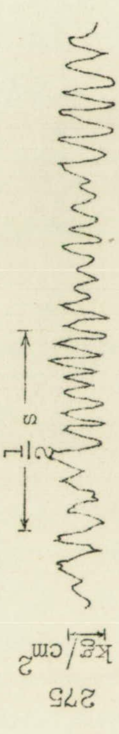

Fig. 27 Microphotograph of elongation scratch diagram, plotted on a diagonal strut.

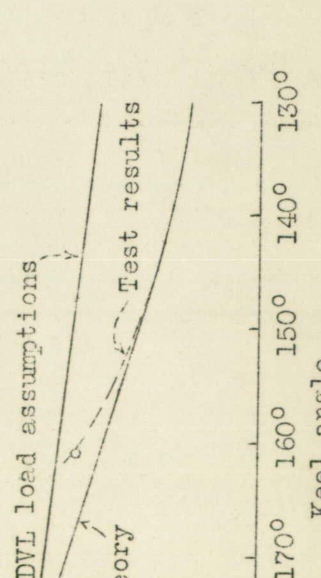

Fig. 24 Effect of keel angle, according to load assumptions, theory and test.

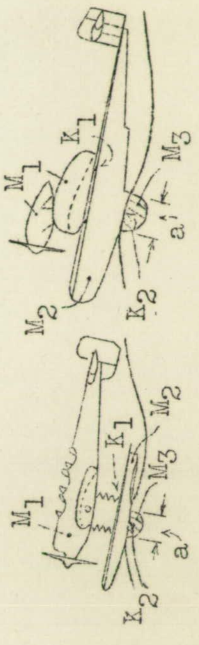

Fig. 28